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Brief Communication

Portable system for monitoring of regional cerebral oxygen saturation during prehospital cardiopulmonary resuscitation: a pilot study

Goro Tajima,[1] Tadahiko Shiozaki,[2] Hiroo Izumino,[1] Shuhei Yamano,[1] Tomohito Hirao,[1] Takamitsu Inokuma,[1] Kazunori Yamashita,[1] Atsuko Nagatani,[1] Mitsuo Onishi,[2] Tomoya Hirose,[2] Takeshi Shimazu,[2] Toshimitsu Hamasaki,[3] and Osamu Tasaki[1]

[1]Emergency Medical Center, Nagasaki University Hospital, Nagasaki; and Departments of [2]Traumatology and Acute Critical Medicine and [3]Biomedical Statistics, Osaka University Graduate School of Medicine, Osaka, Japan

Aim: We aimed to create a system for monitoring of regional cerebral oxygen saturation (rSO_2) in patients with prehospital cardiopulmonary arrest and clarify the changes in rSO_2 during cardiopulmonary resuscitation.

Methods: We measured rSO_2 in cardiopulmonary arrest patients who were transferred by the emergency response vehicle of Nagasaki University Hospital. We developed a portable rSO_2 monitor (HAND ai TOS), which is small enough to carry during prehospital treatment. The sensor is attached to the forehead of the patient and monitors rSO_2 continuously during treatment and transfer.

Results: No difficulties were experienced in monitoring rSO_2 during patient treatment and transfer. Median time (interquartile range) from the emergency medical service call to emergency response vehicle arrival was 15.0 min (11.0–19.5 min). Median rSO_2 on emergency response vehicle arrival at the scene was 46.3% (44.0–48.2%) ($n = 9$; median age, 74.0 years; four men, five women). Median rSO_2 showed significant increase within 5 min after return of spontaneous circulation ($n = 6$, 46.6% versus 58.7%, $P < 0.05$). There was no significant increase in rSO_2 during prehospital cardiopulmonary resuscitation until return of spontaneous circulation was established.

Conclusions: We developed an rSO_2 monitoring system for use during prehospital cardiopulmonary resuscitation. The monitoring system showed a significant increase in rSO_2 after return of spontaneous circulation, whereas there was no significant increase in rSO_2 during cardiopulmonary resuscitation after intubation but before return of spontaneous circulation.

Key words: Cardiopulmonary resuscitation (CPR), near-infrared spectroscopy (NIRS), out-of-hospital cardiac arrest (OHCA), prehospital monitoring, regional cerebral oxygen saturation (rSO_2)

INTRODUCTION

IN RECENT YEARS, near-infrared spectroscopy (NIRS) has been used as a non-invasive technique to estimate cerebral oxygen saturation in many fields.[1,2] In cardiopulmonary resuscitation (CPR), regional cerebral oxygen saturation (rSO_2) may be a predictor of neurological outcome or return of spontaneous circulation (ROSC) in out-of-hospital cardiac arrest (OHCA).[3,4] However, rSO_2 is presently measured only after hospital arrival, and changes in prehospital rSO_2 are unclear. Brain tissue is so susceptible to hypoxia that brain oxygenation must be evaluated and protection of brain tissue started during prehospital CPR. However, there is no way to monitor brain circulation or oxygenation during prehospital CPR. Therefore, we developed a portable NIRS monitoring system that can be carried to the patients by an emergency response vehicle (ERV) and can measure prehospital rSO_2. To our knowledge, this is the first report of the acquisition of prehospital data of cerebral rSO_2 in OHCA.

Corresponding: *Goro Tajima, MD, PhD, Emergency Medical Center, Nagasaki University Hospital, 1-7-1 Sakamoto, Nagasaki 852-8501, Japan. E-mail: gtajima@nagasaki-u.ac.jp.*
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METHODS

Study design and data collection

THIS WAS A prospective observational study undertaken at a single center. The subjects were all cardiopulmonary arrest (CPA) patients who received CPR and were transferred by the ERV of Nagasaki University Hospital (Nagasaki, Japan). The ERV is called by the Emergency Medical Service (EMS) at the same time as the ambulance car when a patient is reported to be in cardiac arrest. On ERV

Fig. 1. Photographs showing the portable near-infrared spectroscopy unit (HAND ai TOS; TOSTEC Co., Japan) which is 170 × 100 × 50 mm in size and 600 g in weight (left panel). The detector consists of two sensors that monitor the bilateral frontal lobes. Medical staff can carry the HAND ai TOS and initiate patient cardiopulmonary resuscitation without difficulty outside the hospital (right panel, red arrow).

arrival, the rSO_2 sensor was attached to the forehead of all patients first, and all patients then received standard advanced cardiovascular life support (ACLS). The rSO_2 was measured continuously by the portable NIRS during prehospital CPR.

We measured the time from reception of the EMS call to ERV arrival and the time from EMS call to hospital arrival. From the continuous rSO_2 data, we analysed the initial rSO_2 value and the values measured every 5 min after tracheal intubation and every 5 min after ROSC.

Portable NIRS

We developed a portable NIRS monitoring system (HAND ai TOS; TOSTEC Co., Ltd, Tokyo, Japan) of only 170 × 100 × 50 mm in size and 600 g in weight that is small enough to accompany the patient during prehospital CPR and transportation. The HAND ai TOS system measures the oxygen saturation based on the Beer–Lambert law, using three different wavelengths of near-infrared LED light, which have specific absorbance to oxyhemoglobin and deoxyhemoglobin. The lights pass through the skin to a depth of approximately 3 cm, and the reflected lights are sensed by a photodiode. The reflected lights represent the haemoglobin information mainly in the cerebral cortex. The system can measure rSO_2 data every second without pulsation, so it is possible to carry out continuous monitoring in CPA patients[5,6] (Fig. 1).

Ethical considerations

This study was permitted by the medical ethics committee of Nagasaki University (No. 12112656). Standard CPR was initiated on all patients according to recommendations of the American Heart Association and the International Liaison Committee on Resuscitation, and medical staff did not change the treatment according to the rSO_2 data.

Statistical analysis

The rSO_2 and time values are expressed as median and interquartile range. The rSO_2 data was analysed using a generalized estimating equation, which is regression analysis of repeated measurements, and changes from baseline are compared by means of a post hoc Bonferroni test. A *P*-value of <0.05 was considered to indicate statistical significance. Statistical analysis was carried out with IBM SPSS Statistics version 19.0 (SPSS, Chicago, IL, USA) and SAS Windows for 9.3 (SAS Institute, Cary, NC, USA).

RESULTS

Patient characteristics and time course

FROM JANUARY TO October 2013, 28 OHCA patients were transferred by ERV, and rSO_2 was monitored successfully in nine patients (Fig. 2). They comprised four men and five women with a median age of 74.0 (70.5–85.0) years. Cardiopulmonary arrest was witnessed in four patients (one with ventricular fibrillation, one with pulseless electrical activity, and two with asystole) and was unwitnessed in the remaining five patients, who were all in asystole. Six patients, including the four witnessed patients, attained ROSC (ROSC group), of whom three attained ROSC before arrival at the hospital. The remaining three patients did not attain ROSC (non-ROSC group). The median time from

EMS call to ERV arrival, that is, the time until initiation of rSO_2 monitoring and ACLS, was 15.0 (11.0–19.5) min. The median time from EMS call to hospital arrival was 35.0 (30.5–45.5) min. Neurological outcome was evaluated using the Glasgow–Pittsburgh cerebral performance category 1 month after admission (Table 1).

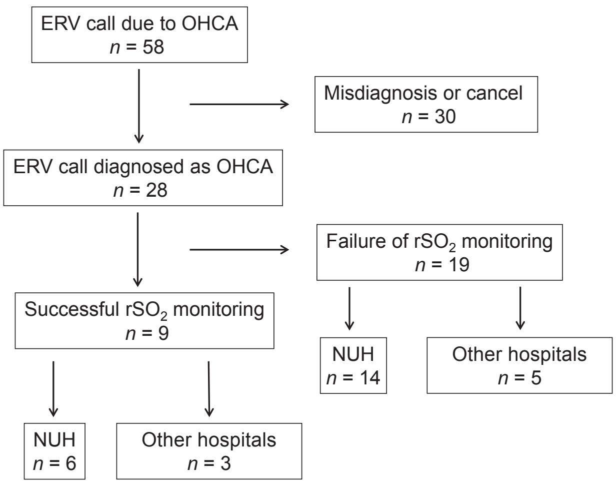

Fig. 2. Overview of out-of-hospital cardiac arrest (OHCA) patients transferred by Emergency Response Vehicle (ERV) of Nagasaki University Hospital (NUH), January–October 2013. rSO_2, regional cerebral oxygen saturation.

Regional cerebral oxygen saturation during prehospital CPR

The rSO_2 sensor was attached to the forehead of each patient on arrival of the ERV, and the medical staff then started to monitor rSO_2 and initiate ACLS (Fig. 1). Median initial rSO_2 was 46.3% (44.0–48.2%). The rSO_2 in the ROSC group increased rapidly after ROSC and at 5 min post-ROSC was already significantly higher than the initial rSO_2 value, (58.7% versus 46.6%, $P < 0.05$) (Fig. 3A). In the non-ROSC group, rSO_2 showed no significant increase in rSO_2, even after intubation during CPR (Fig. 3B). There was no significant increase in rSO_2 during CPR until ROSC, even in the ROSC group.

DISCUSSION

Importance of monitoring prehospital rSO_2

TO OUR KNOWLEDGE, this is the first report of cerebral oxygenation data being obtained during prehospital CPR. There are several important reasons to measure prehospital rSO_2 data. First and foremost, we can determine the change in brain oxygenation in the very early phase after cardiac arrest. The rSO_2 would be expected to change dramatically from cardiac arrest to hospital arrival. Numerous clinical and animal studies have shown that a dynamic change in brain circulation and metabolism occurs after cardiac arrest or during brain ischaemia and reperfusion.[7,8] Therefore, it is necessary to monitor rSO_2 data continuously from the

Table 1. Characteristics and outcome of out-of-hospital cardiac arrest patients transferred by emergency response vehicle of Nagasaki University Hospital, January–October 2013

Patient	Age (years)	Sex	Witness	Rhythm	Bystander CPR	Aetiology	ROSC	Time1[a] (min)	Time2[b] (min)	Outcome
1	80	M	○	VF	○	ACS	○	16	31	CPC5
2	85	F	x	Asystole	x	Unknown	○	14	35	CPC5
3	70	F	x	Asystole	x	Unknown	x	7	33	CPC5
4	71	F	x	Asystole	x	Asphyxia	x	12	37	CPC5
5	71	F	x	Asystole	x	Unknown	x	16	47	CPC5
6	85	M	○	PEA	○	SCI	○	23	44	CPC4
7	52	F	○	Asystole	○	Asphyxia	○	25	52	CPC5
8	90	M	x	Asystole	x	Asphyxia	○	10	30	CPC5
9	74	M	○	Asystole	○	Asphyxia	○	15	27	CPC5
Median (IQR)	74.0 (70.5–85.0)							15.0 (11.0–19.5)	35.0 (30.5–45.5)	

a Duration from emergency medical service call to emergency response vehicle arrival.
b Duration from emergency medical service call to hospital arrival.
CPR, cardiopulmonary resuscitation; M, male; F, female; VF, ventricular fibrillation; PEA, pulseless electrical activity; ACS, acute coronary syndrome; SCI, spinal cord injury; CPC, cerebral performance category.

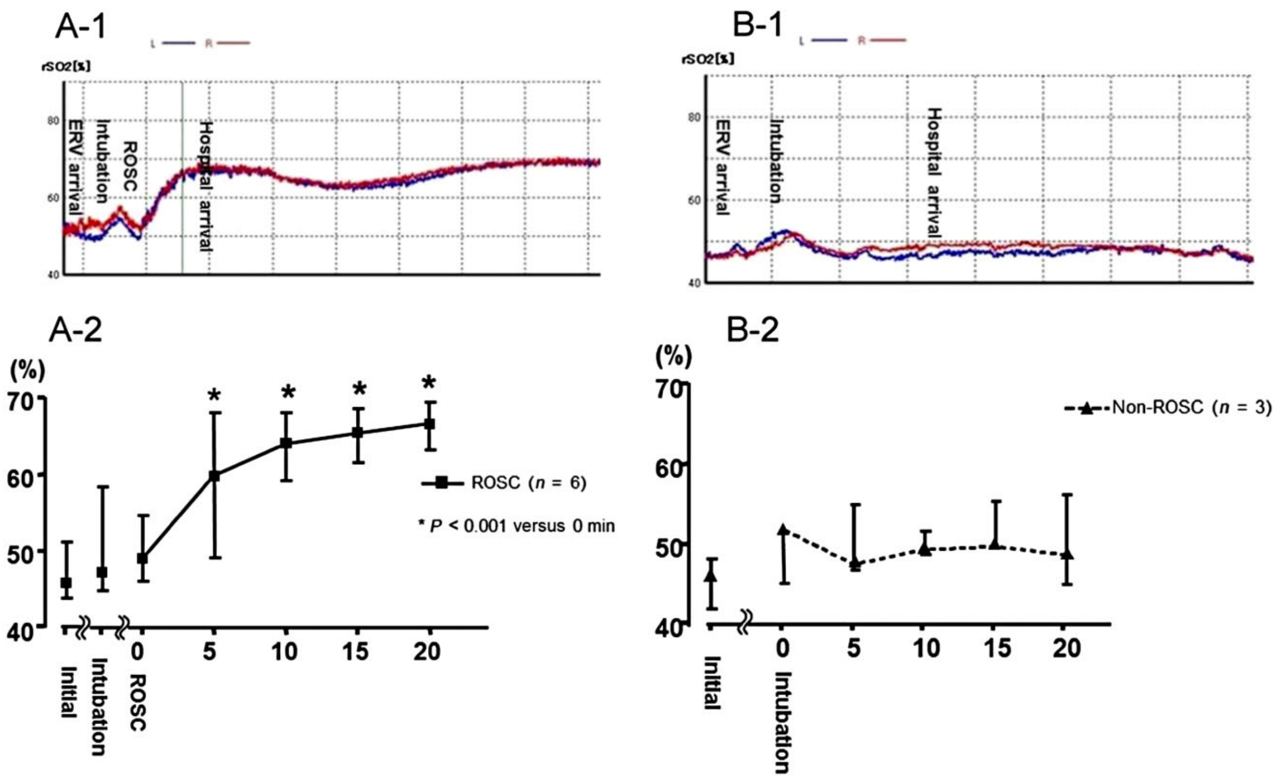

Fig. 3. Regional cerebral oxygen saturation (rSO_2) during prehospital cardiopulmonary resuscitation (CPR) in out-of-hospital cardiac arrest patients transferred by Emergency Response Vehicle (ERV) of Nagasaki University Hospital, January–October 2013. (A-1) Graph from a representative patient in the return of spontaneous circulation (ROSC) group shows rSO_2 signals recorded from the left (L) and right (R) probes of the portable near-infrared spectroscopy unit. (A-2) Graph shows that the rSO_2 had already increased significantly by 5 min after ROSC compared with the initial rSO_2 value (from 46.6% to 58.7%, $P < 0.05$). (B-1) Graph from a representative patient in the non-ROSC group shows no significant change in rSO_2 during CPR. (B-2) During CPR, there was no significant increase in rSO_2 in either group, even after intubation. The rSO_2 values are expressed as median values, and the range is indicated by whisker bars.

prehospital period to understand the pathophysiology of CPA patients and to develop new therapies based on this data. Second, we can evaluate the quality of bystander CPR. Thanks to Basic Life Support education, the importance of bystander CPR is recognized and spreading.[9] The prehospital rSO_2 data may give us clues for further development of more effective bystander CPR. Finally, it may be possible to estimate the time after cardiac arrest in unwitnessed cases. To understand the co-relation between time and rSO_2, it is important to accumulate data from witnessed cardiac arrest patients and to clarify changes in rSO_2 after cardiac arrest. There were only four witnessed arrests in the present study, so more cases are needed to properly evaluate the correlation of rSO_2 value and time after cardiac arrest.

In general, in Japan it takes more than 30 min from the EMS call to patient arrival at the hospital.[10,11] Even though rSO_2 is measured after hospital arrival, it remains unknown how brain oxygenation has changed just after cardiac arrest. In the present study, we could begin to measure rSO_2 within approximately 15 min from the EMS call. Therefore, we can better recognise serial changes in rSO_2 before hospital arrival.

Prehospital rSO_2 data

In the present study, although the rSO_2 value increased dramatically and quickly after ROSC, contrary to our expectations, rSO_2 did not increase significantly after intubation or during CPR. This suggests that the present method of CPR may not be effective for brain resuscitation. Cerebral blood flow during chest compression is reported to be approximately 40% of the normal value;[12] however, it is still not clear whether the measured pressure or flow represents truly effective and forward circulation. A new method of CPR might need to be developed that is effective for resuscitation of both the heart and the brain.

Ito *et al*.[3] reported that neurological outcome was poor when rSO_2 on hospital arrival was lower than 25%. However, in the present study, the initial rSO_2 values in all patients were >40%, which is not very low. This may suggest that, although prehospital CPR did not increase rSO_2 remarkably, it kept the rSO_2 from decreasing. All previously reported data and that in our study were measured after the initiation of chest compression, so it is difficult to know whether conventional CPR itself improves rSO_2.

Our continuous rSO_2 monitoring system showed that ROSC increased rSO_2 markedly, and it was easy to distinguish ROSC by the change in rSO_2, which suggests that we might be able to ascertain ROSC without checking the pulse, and thus, chest compressions would not need to be stopped to check this. Interruption of chest compression deteriorates outcome of CPA patients.[13,14] For this reason, recognition of ROSC according to rSO_2 may improve the outcome of patients with OHCA.

Limitations

As limitations of the present study, in addition to the small sample size, no patients experienced good recovery, so we could not analyse the co-relation between rSO_2 data and outcome. In the present study, blood pressure, oxygen saturation by pulse oximetry, and blood gas data were not measured in consistent time points, so we could not evaluate the correlation between rSO_2 and those factors. Although we measured rSO_2 data continuously, we still do not know the rSO_2 values before starting chest compression or how much time had passed from cardiac arrest to initiation of chest compression.

CONCLUSIONS

WE DEVELOPED A portable rSO_2 monitoring system for use in prehospital CPR that could become routine for prehospital monitoring of patients with OHCA. The system showed that rSO_2 values increased immediately and significantly after ROSC but did not increase significantly during CPR in patients with or without ROSC even after intubation. Further investigation is required to clarify brain oxygenation in OHCA patients.

CONFLICT OF INTEREST

NONE.

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